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Task 1 is now complete.

Two alternatives to the problem of limited dual-junction performance are under consideration. A change in the tunnel junction eliminates the need for reactor modification, which is the other alternative. Changing the tunnel junction has been incorporated into the design of the dual-junction cell and the cell will be processed during the next reporting period.

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InGaP/InGaAs-on-Ge Concentrator Solar Cell for Space Power Generation

Contract—

NAS3-99174

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Date—

April 12, 2000

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WORK PERFORMED THIS PERIOD

Task 1—Growth and characterization of a lattice-matched passivating window for InGaP

$\text{Al}_{0.33}\text{In}_{0.67}\text{P}$ has been chosen as the lattice-matched passivating front and back window layer of the 1.62 eV InGaP top cell. This task is now complete.

Task 3—Growth and characterization of InGaAs tunnel junction

In the previous report, we presented the results of a two-terminal n/p InGaP/InGaAs dual-junction cell using a p++/n++ $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$ tunnel junction. InGaAs was chosen as the tunnel junction interconnect compound since it is easily degenerately doped. air-mass zero (AM0), one-sun efficiency of this dual-junction cell was measured to be 19%, and it was found to be bottom-cell current limited. A detailed analysis of the results identified several factors that were causing performance degradation. These factors were listed in the previous report.

One important factor limiting the performance of our dual-junction cell was the use of 1.1 eV InGaAs tunnel junction, which absorbs some of the red light that the bottom cell is designed to convert. Calculations indicated that the use of a non-absorbing tunnel junction (such as 1.62 eV InGaP) would result in a 6% increase in the short circuit current (J_{sc}) of the bottom cell. However, because of limitations in the NASA metal organic vapor phase epitaxy (MOVPE) reactor currently being used for this project, it is not possible to grow a p++ InGaP layer required for the tunnel junction. We are currently exploring two alternatives to overcome this limitation as described below.

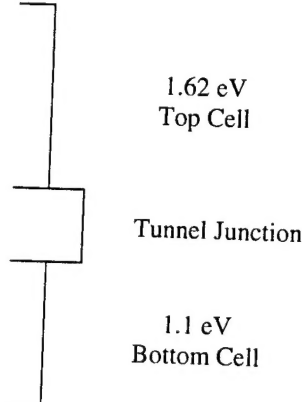
- **Reactor modification:** The installation of a “double-dilution” line from the diethyl zinc (DEZn) precursor will allow us to increase the p-doping range from $1 \times 10^{17}/\text{cm}^3$ (needed for base-doping) to $1 \times 10^{19}/\text{cm}^3$ (needed for the tunnel junction). This modification should be complete in late spring or early summer of this year.
- **P++ AlGaAs/n++ InGaP tunnel junction:** This alternative eliminates the need for reactor modification, although AlGaAs is not lattice-matched to the subsequent 1.62-eV InGaP top cell structure. However, since the AlGaAs layer will be very thin (0.02 μm), the InGaP layer is expected to grow pseudomorphically on it, without any degradation in its crystalline quality. Another problem associated with the use of aluminum containing alloys is that they usually have a higher oxygen content, and the oxygen might act as a recombination center, causing performance degradation. Thus, our goal was to keep the aluminum content in the AlGaAs at the minimum acceptable level for the tunnel junction. After several calibration runs, we have settled on $\text{Al}_{0.09}\text{GaAs}$. Composition and thickness calibrations were made by ellipsometry. Photoluminescence measurement showed that the bandgap was 1.55-eV. We

were able to achieve a maximum p-doping of $8.2 \times 10^{18}/\text{cm}^3$ in this material. Thus, it is suitable for the p++ component of the tunnel junction.

Task 4—Fabrication and testing of two-terminal InGaP/InGaAs monolithic tandem cells on GaAs substrates.

Figure 1 shows a schematic diagram of the current design of our dual-junction cell. The 1.1 eV bottom cell is comprised of a $0.5 \mu\text{m}$ n+ $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$ emitter, a $3.0 \mu\text{m}$ p $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$ base and a $0.05 \mu\text{m}$ $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$ window layer. The 1.62 eV top cell consists of a $0.05 \mu\text{m}$ n+ $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$ emitter, a $0.275 \mu\text{m}$ p $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$ base, a $0.05 \mu\text{m}$ p+ $\text{In}_{0.68}\text{Ga}_{0.32}\text{P}$ back surface field, and a $0.04 \mu\text{m}$ n $\text{Al}_{0.33}\text{In}_{0.67}\text{P}$ window layer. We have thinned the top cell in the current junction cell. A p++/n++ AlGaAs/InGaP tunnel junction structure has been incorporated in the dual-junction cell. All of the dual-junction cell structures were grown on GaAs substrates.

Contact		
n++	In _{0.2} Ga _{0.8} As	0.1 μm
n	Al _{0.33} In _{0.67} P	0.04 μm
n+	In _{0.68} Ga _{0.32} P	0.05 μm
p	In _{0.68} Ga _{0.32} P	0.275 μm
p+	In _{0.68} Ga _{0.32} P	0.05 μm
p	Al _{0.33} In _{0.67} P	0.05 μm
p++	Al _{0.09} GaAs	0.02 μm
n++	In _{0.68} GaP	0.02 μm
n+	In _{0.68} Ga _{0.32} P	0.05 μm
n	In _{0.2} Ga _{0.8} As	0.5 μm
p	In _{0.2} Ga _{0.8} As	3.0 μm
p	In _{0.68} Ga _{0.32} P	0.05 μm
Buffer Scheme		
p	GaAs	
6° off towards (111)B		
Contact		



1.62 eV
Top Cell

Tunnel Junction

1.1 eV
Bottom Cell

Figure 1.—Epi-layer structure of the 1.62 eV InGaP/1.1 eV InGaAs dual-junction cell.

WORK TO BE PERFORMED DURING THE NEXT REPORTING PERIOD

During the next reporting period, the emphasis will be on processing of the thinned dual-junction cell with the new tunnel-junction configuration, followed by testing under 1 to 20 sun concentrations. The cell structures and processing parameters will continue to be optimized to realize the highest possible efficiency values under concentrator conditions. However, it appears likely that we will need to request a no-cost extension of the program by three months, to bring it to a successful completion.

Cost and Completion Estimates

The current costs have been calculated and the estimates are as follows:

- Total Costs (cumulative) through March 22, 2001 \$ 150,930
- Estimated Costs for the following quarter..... \$ 50,000
- Estimated Costs to the contract completion \$ 149,056
- Estimated physical completion through March 22, 2001 51%